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TECHNICAL NOTE

D-961

TRANSONIC WIND-TUNNEL TESTS OF AN ERROR-COMPENSATED STATIC-PRESSURE PROBE

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON August 1961

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SUMMARY

An investigation of the pressure-sensing characteristics of an error-compensated static-pressure probe mounted on the nose section of a missile body has been conducted in the Langley 16-foot transonic tunnel. The probe was free to rotate about its roll axis and was equipped with a vane so that the crossflow velocity component due to angles of attack or sideslip was always alined with the probe's vertical plane of symmetry. The probe was tested in five axial positions with respect to the missile nose at Mach numbers from 0.30 to 1.08 and at angles of attack from -2.7° to 15.3°. The test Reynolds number per foot varied from 1.79×10^{6} to 4.05×10^{6}.

Results showed that at a Mach number of 1.00 the static-pressure error decreased from 3.5 percent to 0.8 percent of the free-stream static pressure, as a result of a change in orifice location from 0.15 maximum missile diameter to 0.20 maximum missile diameter forward of the missile nose. Although compensation for pressure-sensing errors due to angles of attack up to 15.3 was maintained at Mach numbers from $M = 0.30$ to $M = 0.50$, there was an increase in error with an increase in angle of attack for Mach numbers between $M = 0.50$ and $M = 1.08$.

INTRODUCTION

For conventional static-pressure probes located forward of the nose of a fuselage or missile, the static-pressure error increases with Mach number up to the low supersonic Mach number at which the bow shock wave moves to the rear of the static-pressure orifices. In reference 1 it was shown that, at an angle of attack of 0° and with the orifices at a position as short as 0.27 maximum vehicle diameter ahead of the vehicle, the static-pressure errors could be compensated for throughout the subsonic Mach number range and could be kept to within 1 percent of the free-stream static pressure at $M = 1.0$ by the use of an ogival-nose probe with orifices located on the curved section of the nose.

The investigation of reference 1 also showed that the static-pressure errors of the ogival-nose probe as a result of angle of attack could be compensated for through an angle-of-attack range of 0° to 4° by the use of an orifice arrangement consisting of two pressure-sensing orifices located on the lower surface of the probe at $\pm 37.5^{\circ}$ from the probe vertical plane of symmetry. However, the static-pressure error I
of this orifice configuration at angles of sideslip and at angles of 1
roll in combination with angles of attack are comparatively large. It 5
was therefore suggested in reference 1 that the probe be allowed to 6
rotate about its longitudinal axis in order to maintain the orifice 2
arrangement at $\pm 37.5^{\circ}$ from the crossflow velocity component due to angle of attack or sideslip. One possible configuration, consisting of a rotating mechanism and a single vane mounted on the rear of the probe for maintaining this alinement, was suggested in reference 2.

For the purpose of investigating the practical application of a self-rotating error-compensated probe, the Langley Research Center has conducted wind-tunnel tests of a probe utilizing one of the ogival nose sections reported in reference 1 and a rotating mechanism similar to that described in reference 2. The probe was tested forward of the nose section of a missile, at five axial positions within the region for which the Mach number compensation was estimated to be the greatest. The present tests were conducted at Mach numbers from 0.30 to 1.08 and at angles of attack from -2.7° to 15.3°. The test Reynolds number per foot varied from 1.79×10^{6} to 4.05×10^{6}.

SYMBOLS

D	maximum diameter of missile, 20.50 in.
M	free-stream Mach number
p	local static pressure measured by probe, lb/sq ft
p_{∞}	free-stream static pressure, lb/sq ft
x	longitudinal distance between orifice and nose of missile, in.
α	missile angle of attack, deg

MODELS

Probe

A sketch of the self-rotating probe, which was mounted on the nose of the missile, is shown in figure 1. The probe had a cylindrical body, 0.375 inch in diameter, and an ogive nose. Two orifices, 0.42 inch in diameter, were located on the ogive surface 0.93 inch from the tip of the probe. (The shape of the nose section and the axial location of the orifices are the same as those of probes 4 and 5 of ref. 1.) The probe was tested in five axial positions, 3.01, 3.26, 3.51, 3.76, and 4.01 inches forward of the nose of the missile, as shown in figure 1.

The radial position of the two orifices was $\pm 37.5^{\circ}$ from the vertical plane of symmetry on the lower surface of the probe (same orifice arrangement as probe 5C of ref. 1). In order to maintain the angle-of-attack compensation at angles of sideslip and at angles of roll in combination with angles of attack, a single vane was attached at the rear of the probe. A system of bearings allowed the probe to rotate about its own roll axis. "O" rings were used to prevent leakage in the pressure transfer between the rotating probe and the tubing in the missile.

Missile Body

A sketch of the missile body and support system is shown in figure 2. The forward part of the missile consisted of a series of conical sections and the missile terminated with a cylindrical section having the maximum missile diameter of 20.50 inches. A photograph of the model with the probe installed is shown in figure 3.

APPARATUS AND ACCURACIES

The present investigation was conducted in the Langley 16-foot transonic tunnel, which is a single-return atmospheric wind tunnel with a slotted octagonal test section. The speed range of this tunnel is from a Mach number of 0.20 to 1.10, with Mach number being varied over this range by a variation of tunnel drive power. The model was supported in the tunnel as shown in figure 2, and was pivoted in such a manner that a point on the missile body (labeled axis of rotation in fig. 2) was kept on or near the tunnel center line throughout the angle-of-attack range.

A differential pressure gage was used to measure the difference between the pressure sensed by the probe and the tunnel tank static pressure. Free-stream static pressure was determined from the calibration of the tunnel tank static pressure. Mach number was determined from a calibration of the difference between tunnel stagnation pressure and tunnel tank static pressure. A pendulum-type strain-gage inclinometer was located inside the missile in order to determine the angle of attack.

The accuracies of the measurements have been estimated to be:

$\frac{p - p_\infty}{p_\infty}$ . . . . ± 0.005
M . . . . ± 0.003
α, deg . . . . ± 0.10

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RESULTS AND DISCUSSION

The results of the tests of the probe, for each of the five axial probe positions, are presented in figures 4 to 8. The variation of the static-pressure error coefficient $\frac{p - p_\infty}{p_\infty}$ with Mach number at $\alpha = 0^\circ$ is given for the five probe positions, and, in addition, the variation of $\frac{p - p_\infty}{p_\infty}$ with angle of attack is given for Mach numbers between 0.30 and 1.08.

Figures 4 to 8 show that the static-pressure error coefficient of the probe at $\alpha = 0^\circ$ for each of the five axial positions increases with Mach number up to $M = 1.00$. For any given Mach number, the magnitude of the coefficient generally decreases with an increasing distance of the probe from the nose of the missile. At $M = 1.00$ the pressure error coefficient decreased from 3.5 percent of the free-stream static pressure for $x/D = 0.15$ to 0.8 percent of the free-stream static pressure for $x/D = 0.20$, as can be seen from a comparison of figures 4(a) and 8(a). From the variation of $\frac{p - p_\infty}{p_\infty}$ with x/D at Mach numbers of 0.70, 0.90, and 1.00 (fig. 9), it would appear that the optimum position for complete Mach number compensation with this probe on the missile body is about $x/D = 0.207$.

At a Mach number of 1.05, the coefficients at all five positions have values of about -0.08. Since, at this Mach number, the bow shock wave has passed to the rear of the static-pressure orifices, this coefficient represents the error of the isolated probe at this Mach number.

Compensation for errors due to angles of attack from -2.7° to 15.3° was maintained for Mach numbers up to $M = 0.50$ for all five probe positions. (See figs. (4) to (8).) For Mach numbers greater than $M = 0.50$, the error coefficient increased positively with an increase in angle of attack except for probe position 2 at $M = 1.05$. For $M = 0.50$ to 1.00, the increase in the error coefficient with angle of attack at a given Mach number is approximately the same for each of the five probe positions. For example, at $M = 1.00$ the increase in the error for angle of attack between 0° and 15.3° is about 0.030 for each of the five probe positions.

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These results indicate that the $\pm 37.5^{\circ}$ orifice arrangement does not provide satisfactory angle-of-attack compensation for angles of attack as high as 15.3° in the Mach number range of 0.50 to 1.00. As the results of the tests of references 3 and 4 indicate that the orifice radial position for compensation of pitch and sideslip increases as the distance from the nose of an ogival-nose probe decreases, it would appear that for an improvement in the angle-of-attack compensation of the present probe the angle between the orifices and the vertical plane of symmetry of the probe should be greater than 37.5°.

CONCLUSIONS

An investigation to determine the pressure-sensing characteristics of a self-rotating static-pressure probe designed to give compensation for static-pressure errors due to Mach number and angle of attack indicated the following conclusions:

1. At $M = 1.00$, a decrease from 3.5 percent to 0.8 percent error in static pressure was found by moving the orifice location from 0.15 maximum missile diameter to 0.20 maximum missile diameter forward of the missile body.

2. For an angle-of-attack range up to 15.3°, compensation for errors due to angle of attack was maintained from $M = 0.30$ to 0.50, with positive increases in static-pressure error occurring with an increase in angle of attack for Mach numbers greater than 0.50 and up to $M = 1.08$.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., April 26, 1961.

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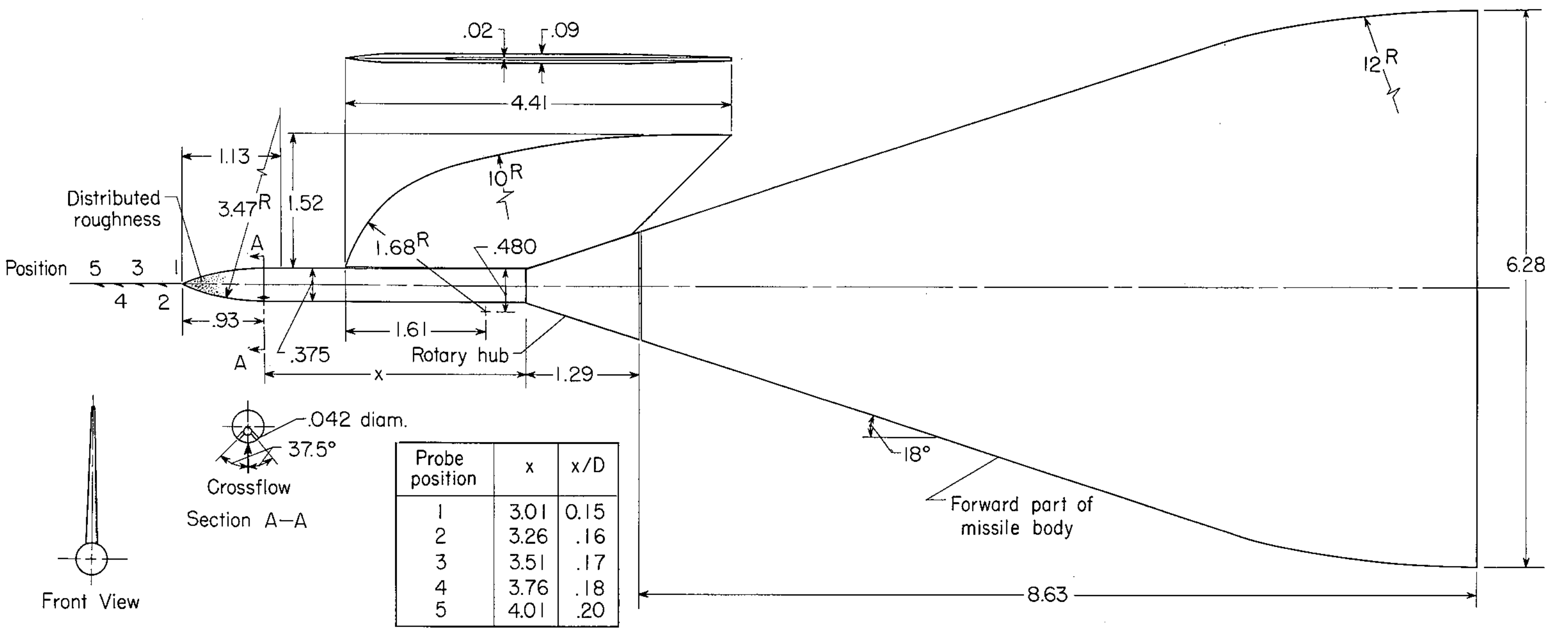
1. Ritchie, Virgil S.: Several Methods for Aerodynamic Reduction of Static-Pressure Sensing Errors for Aircraft at Subsonic, Near-Sonic, and Low Supersonic Speeds. NASA TR R-18, 1959.

2. Compitello, Frank E.: An Evaluation of Various Aerodynamic Probes Considered for Baro-Fuzing a LaCrosse Missile Equipped With a T52 Warhead. Tech. Memo. No. 28, Feltman Res. and Eng. Labs., Picatinny Arsenal (Dover, N.J.), May 1959.

3. Robinson, Harold L.: Pressures and Associated Aerodynamic and Load Characteristics for Two Bodies of Revolution at Transonic Speeds. NACA RM L53L28a, 1954.

4. Cooper, Morton, and Hamilton, Clyde V.: Orientation of Orifices on Bodies of Revolution for Determination of Stream Static Pressure at Supersonic Speeds. NACA TN 2592, 1952.



Probe position	x	x/D
1	3.01	0.15
2	3.26	.16
3	3.51	.17
4	3.76	.18
5	4.01	.20

Figure 1.- Sketch of self-rotating probe. All dimensions in inches unless otherwise noted.

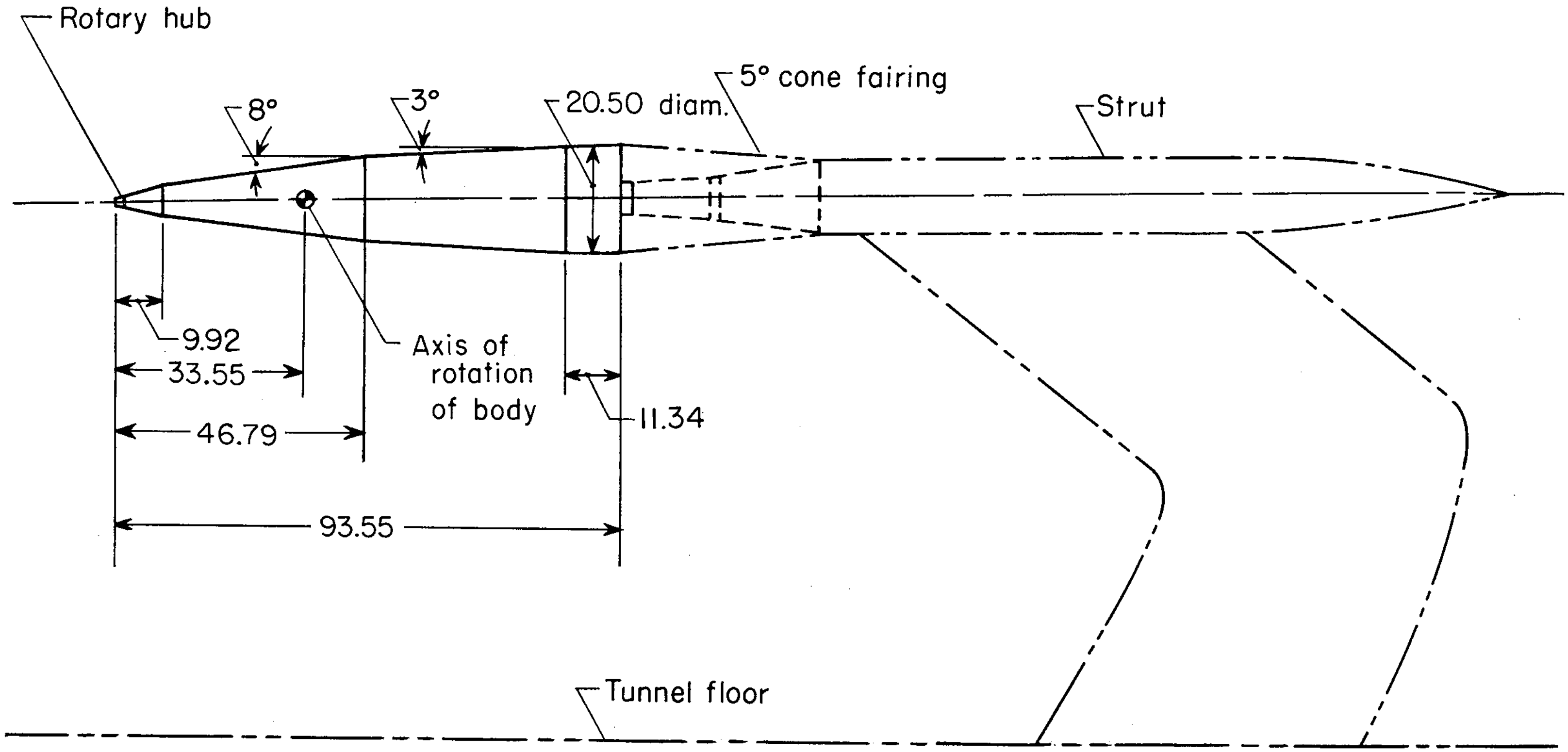


Figure 2.- Sketch of missile body and support system. All dimensions in inches unless otherwise noted.

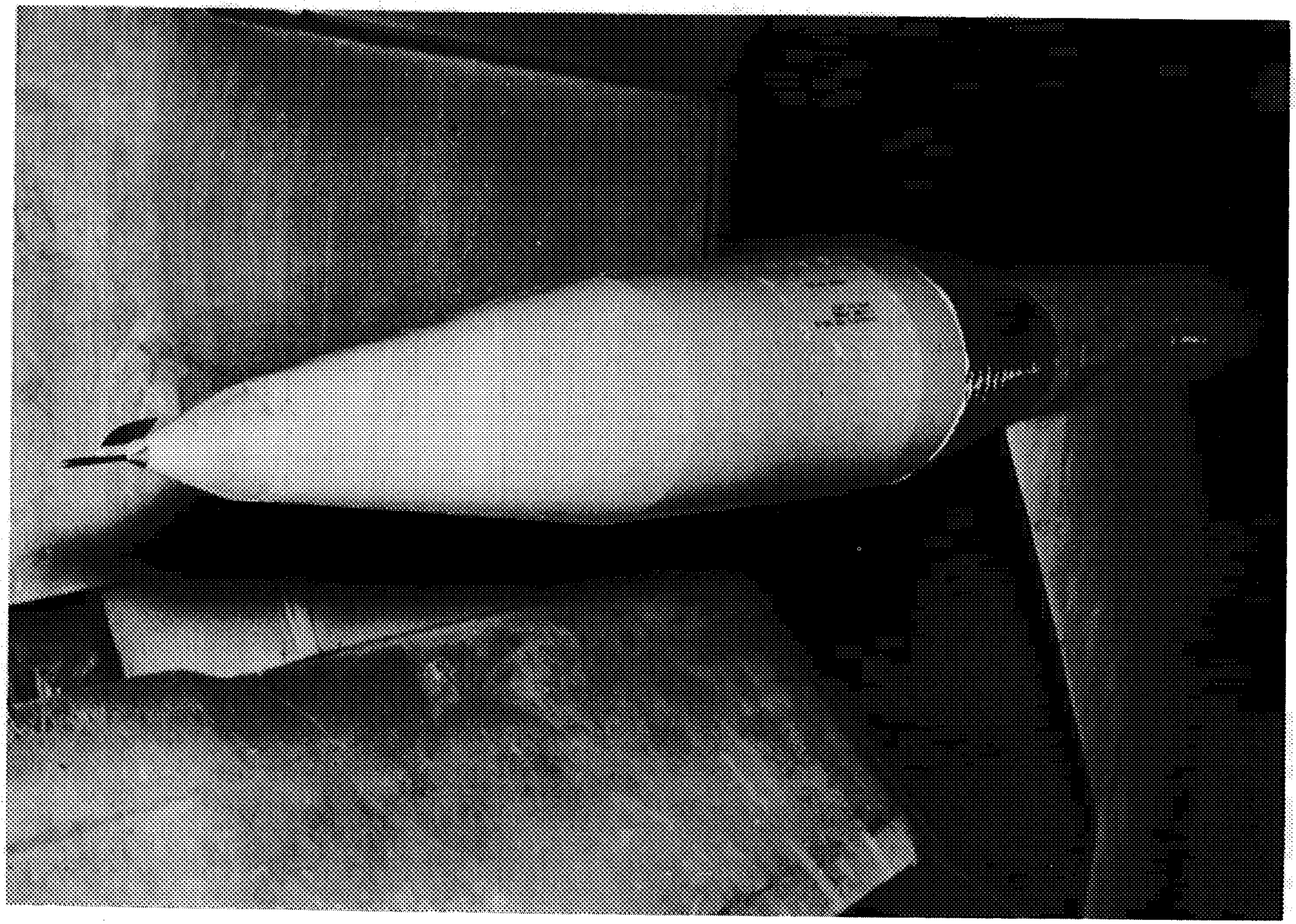


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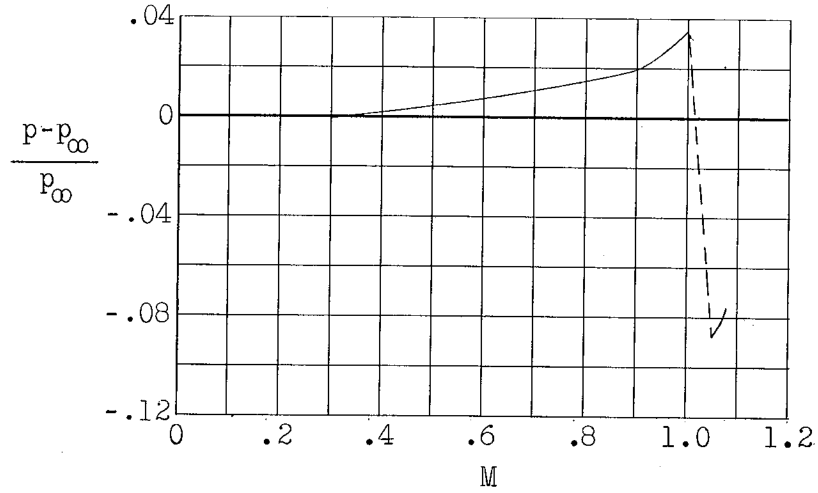
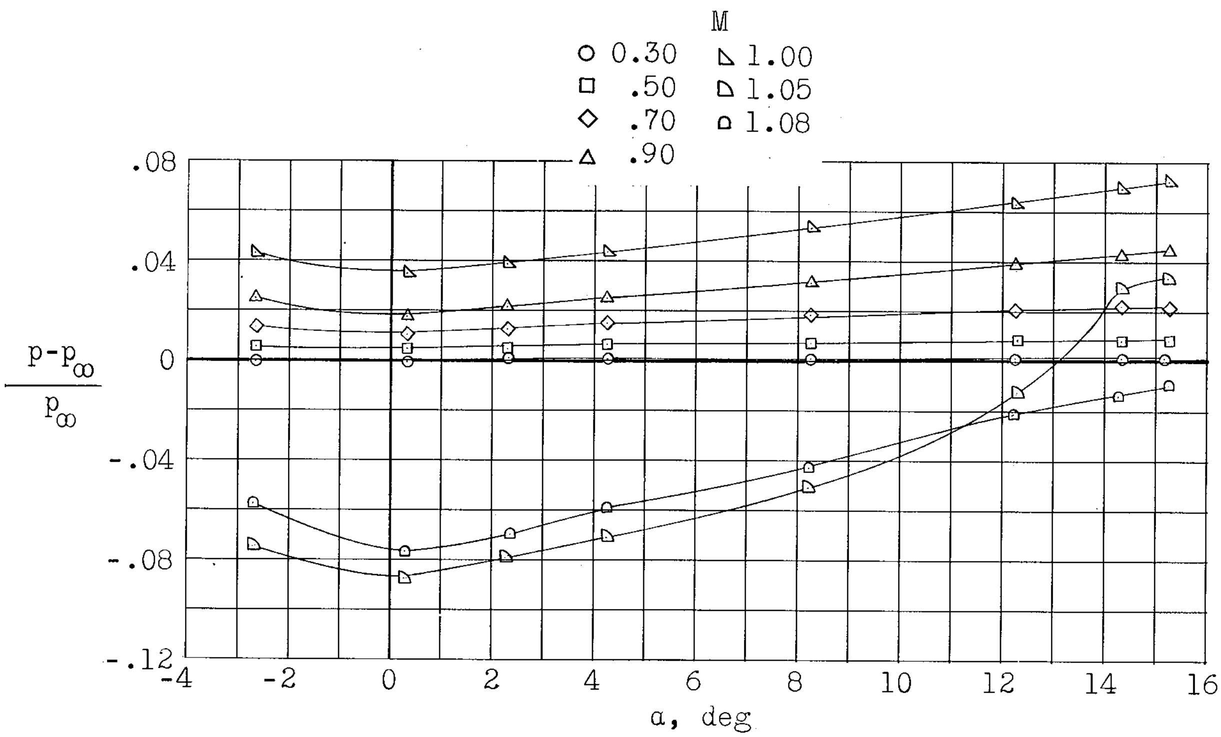
Figure 3.- Photograph of missile body mounted in the Langley 16-foot transonic tunnel with the self-rotating probe.



(a) Effect of Mach number at $\alpha = 0^\circ$.



(b) Effect of angle of attack at various Mach numbers.

Figure 4.- Variation of static-pressure error coefficient $\frac{p - p_\infty}{p_\infty}$ with Mach number and angle of attack for probe position 1 (x/D = 0.15).

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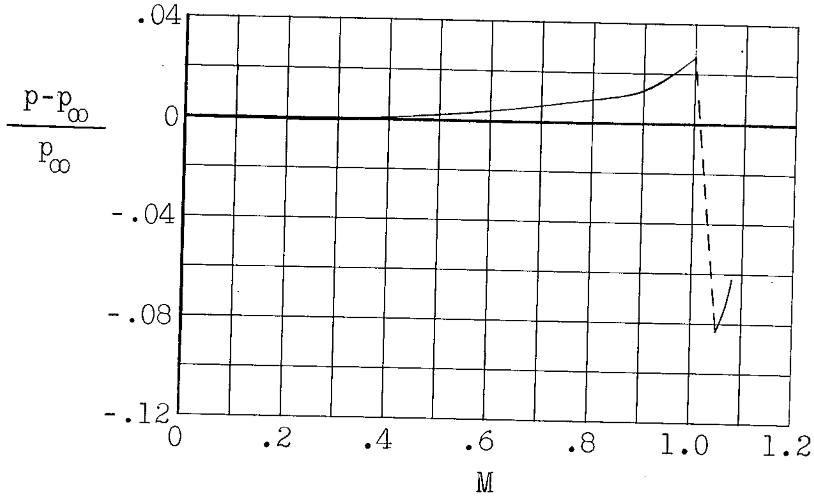
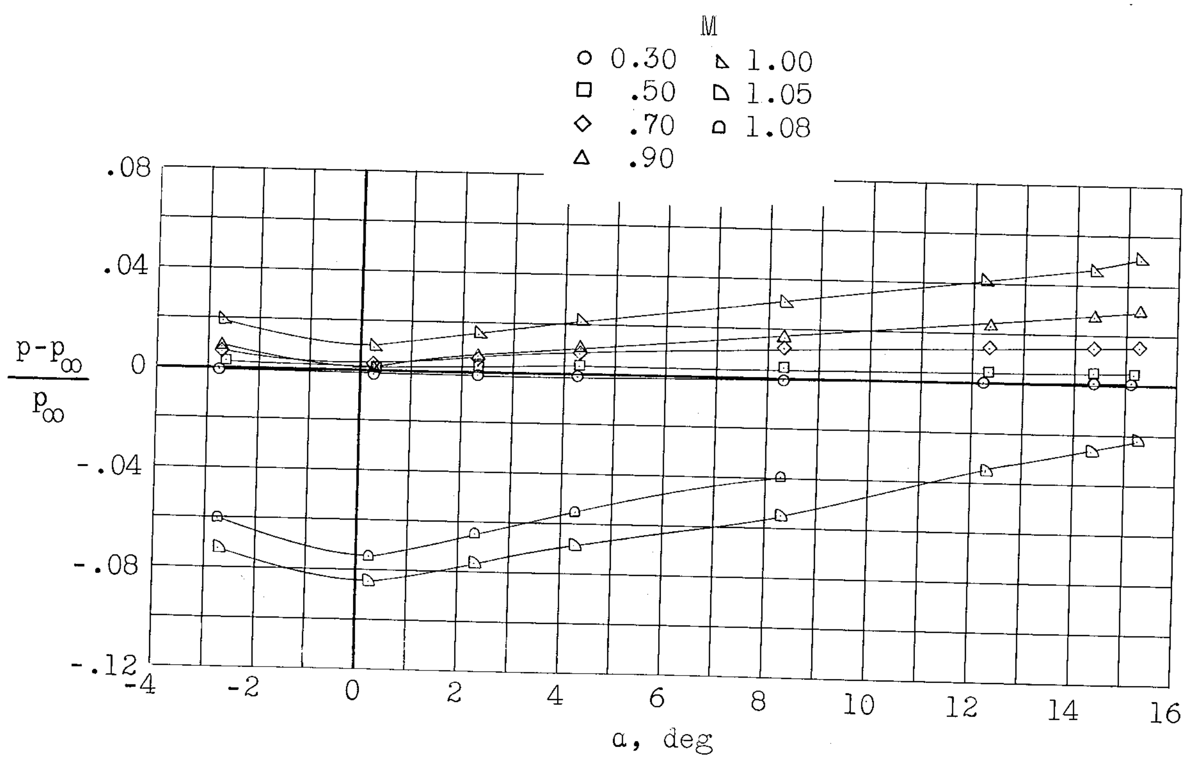
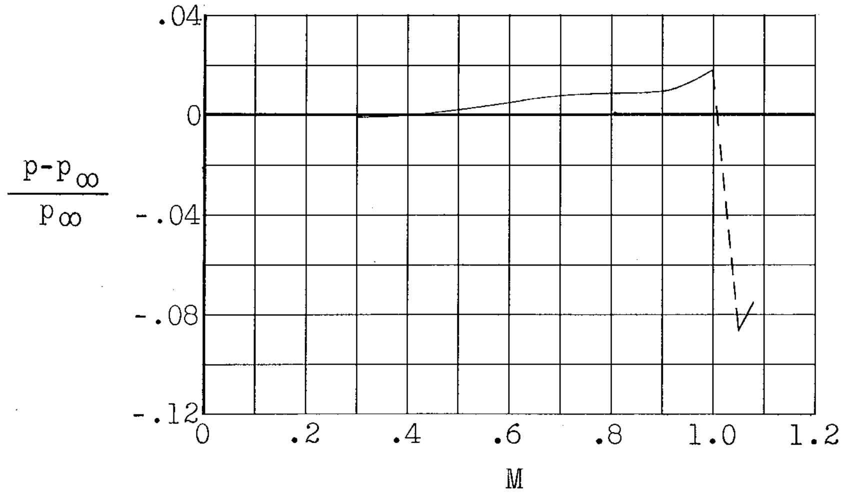


(a) Effect of Mach number at $\alpha = 0^{\circ}$.

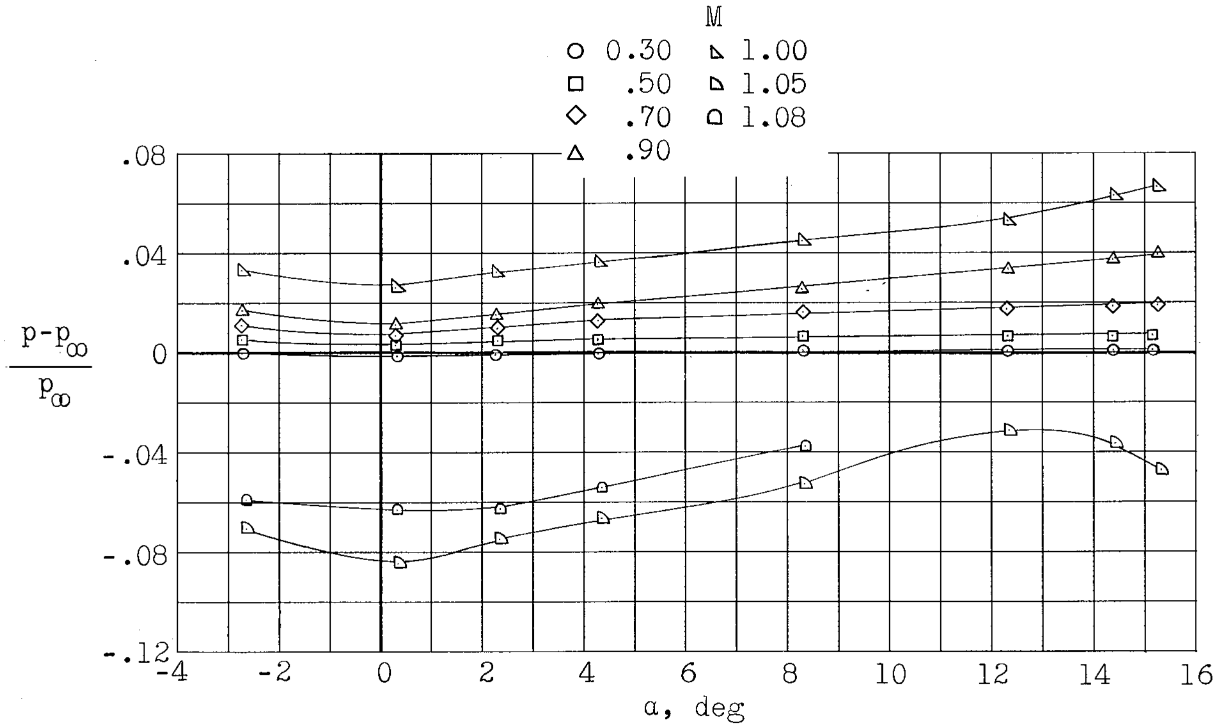


(b) Effect of angle of attack at various Mach numbers.

Figure 5.- Variation of static-pressure error coefficient $\frac{p - p_\infty}{p_\infty}$ with Mach number and angle of attack for probe position 2 (x/D = 0.16).

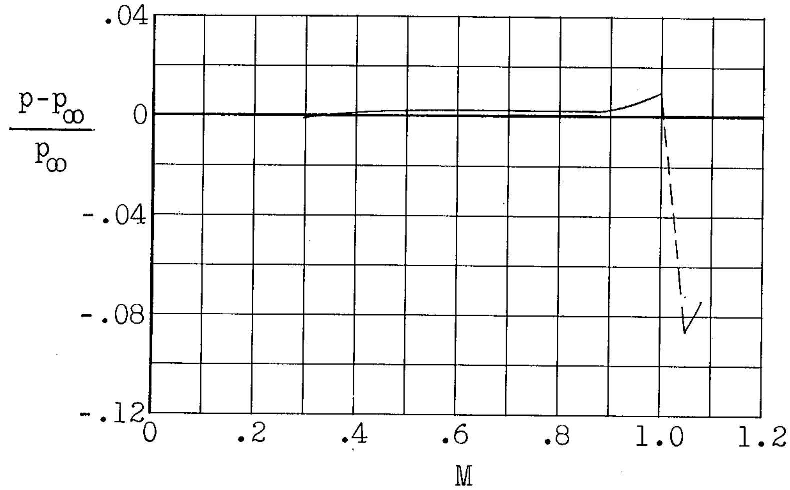


(a) Effect of Mach number at $\alpha = 0^{\circ}$.

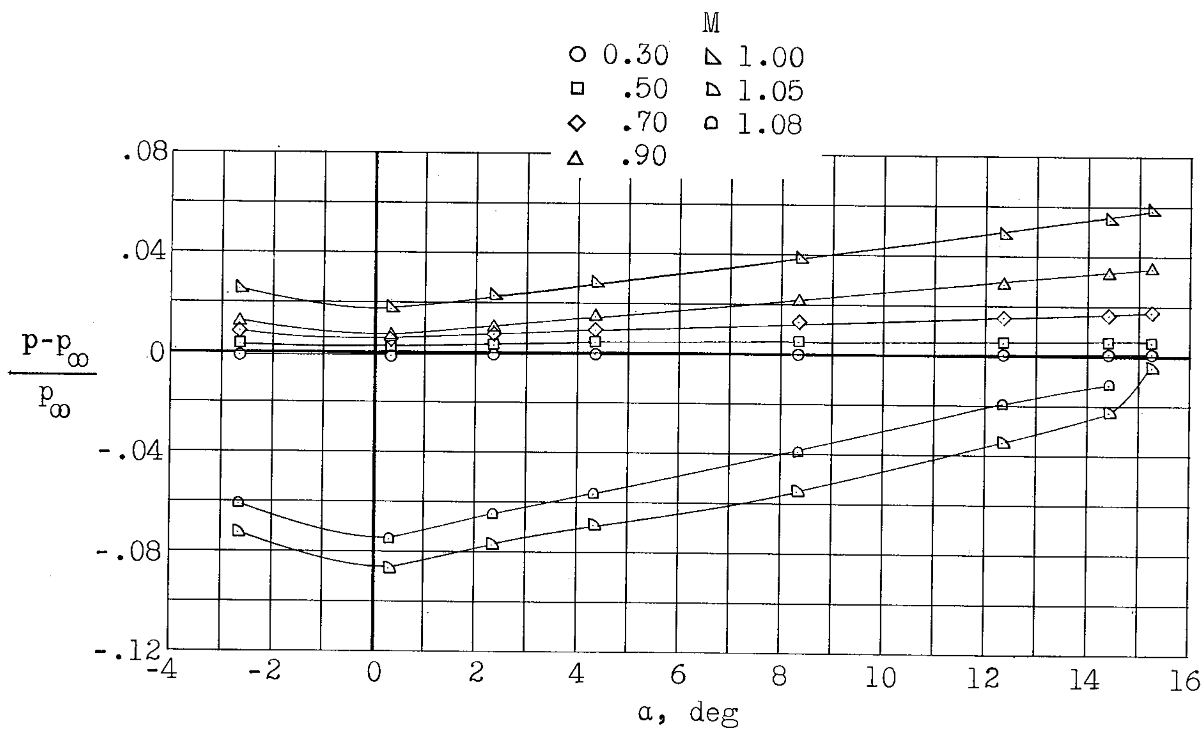


(b) Effect of angle of attack at various Mach numbers.

Figure 6.- Variation of static-pressure error coefficient $\frac{p - p_\infty}{p_\infty}$ with Mach number and angle of attack for probe position 3 (x/D = 0.17).

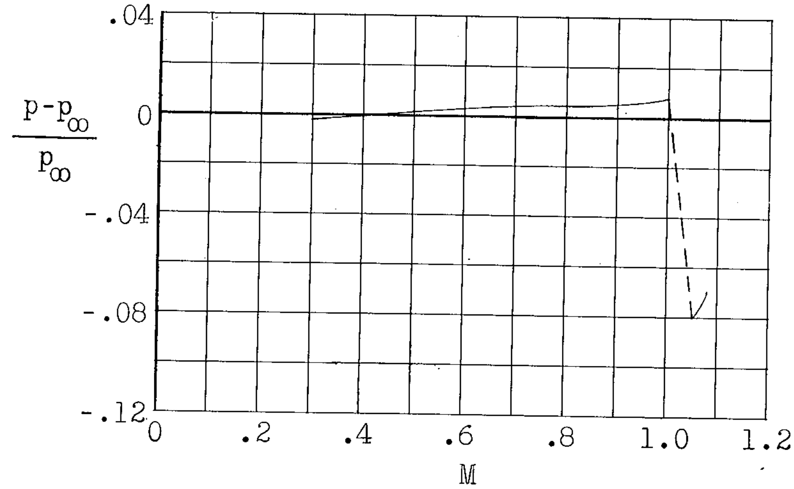


(a) Effect of Mach number at $\alpha = 0^{\circ}$.

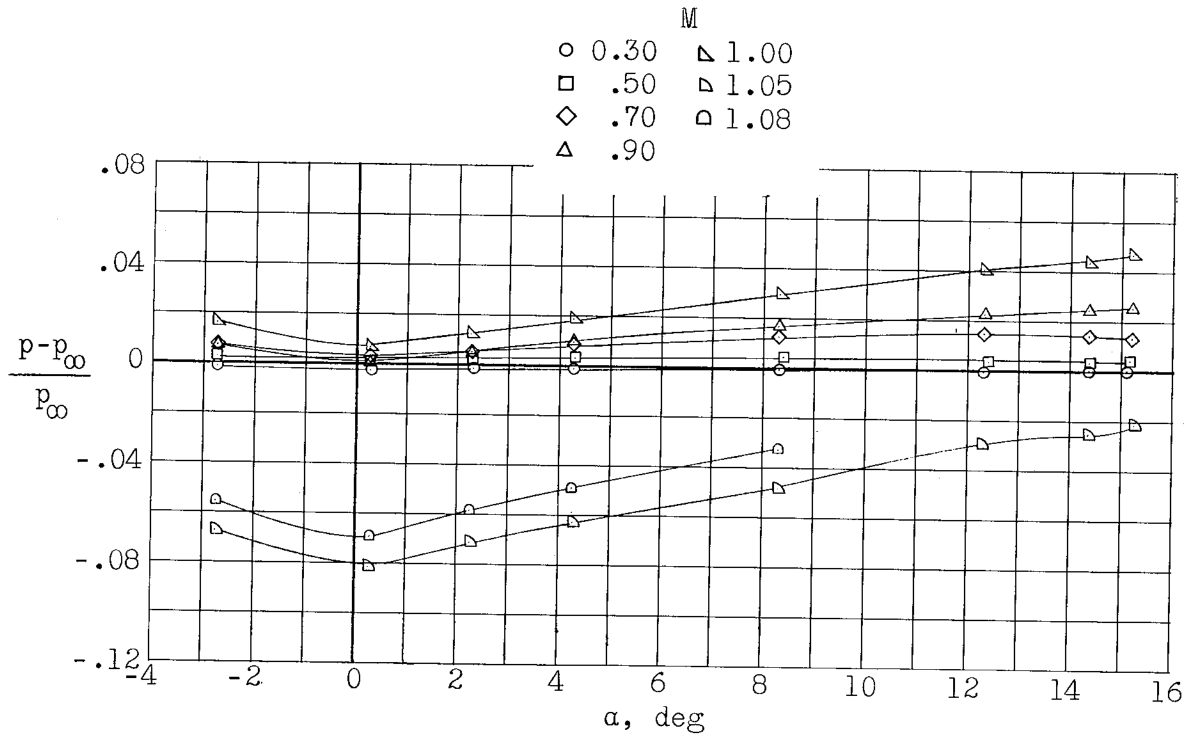


(b) Effect of angle of attack at various Mach numbers.

Figure 7.- Variation of static-pressure error coefficient $\frac{p - p_\infty}{p_\infty}$ with Mach number and angle of attack for probe position 4 ($x/D = 0.18$).



(a) Effect of Mach number at $\alpha = 0^\circ$.



(b) Effect of angle of attack at various Mach numbers.

Figure 8.- Variation of static-pressure error coefficient $\frac{p - p_\infty}{p_\infty}$ with Mach number and angle of attack for probe position 5 (x/D = 0.20).

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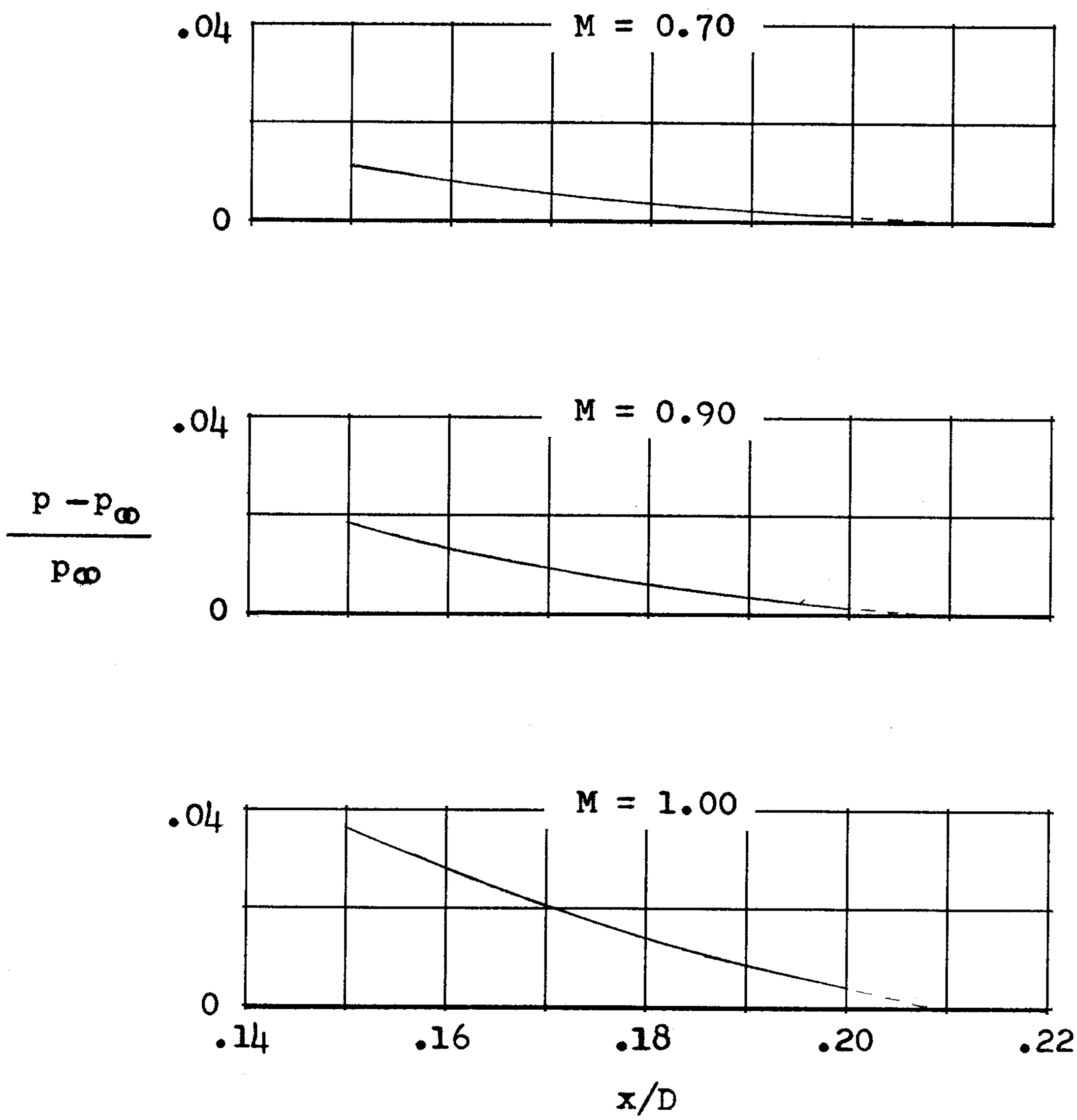

Figure 9.- Variation of $\frac{p - p_\infty}{p_\infty}$ with x/D for various Mach numbers at $\alpha = 0^\circ$.

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